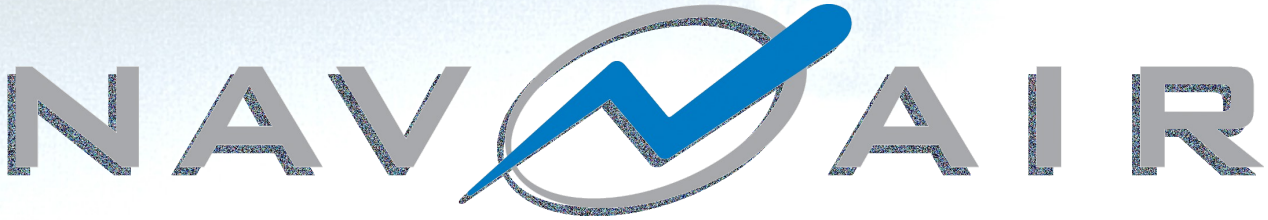
Progress on Development of a Sub-scale Fast Cook-off Test



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NDIA Insensitive Munitions & Energetic Materials Technology Symposium
15-18 October 2007

Outline

- **Introduction/Background**
- **Thermal Apparatus**
- **Calibration**
- **Test Articles**
- **Preliminary Results**
- **Summary**
- **Future Work**

Introduction

- **Progress on effort to develop a controlled fast cook-off test**
  - **Year 3 of 5 year effort**
- **Supports efforts to develop a subscale alternate test protocol for external fire test used in final hazards classification**
  - **DDESB/JANNAF**
  - **Air Force**
  - **Army**
  - **Navy**

Background

- **Hazard Classification - Assignment of HD 1.1 through 1.4**
  - **Liquid fuel/external fire test**
- **Insensitive Munitions (IM)**
  - **Fast cook-off**
- **Move to harmonize the testing**

System Level Tests

- **Expensive**
- **Late in development phase**
  - **Difficult to make changes**
- **Few tests**
  - **Results may be misleading**

Why Bother?

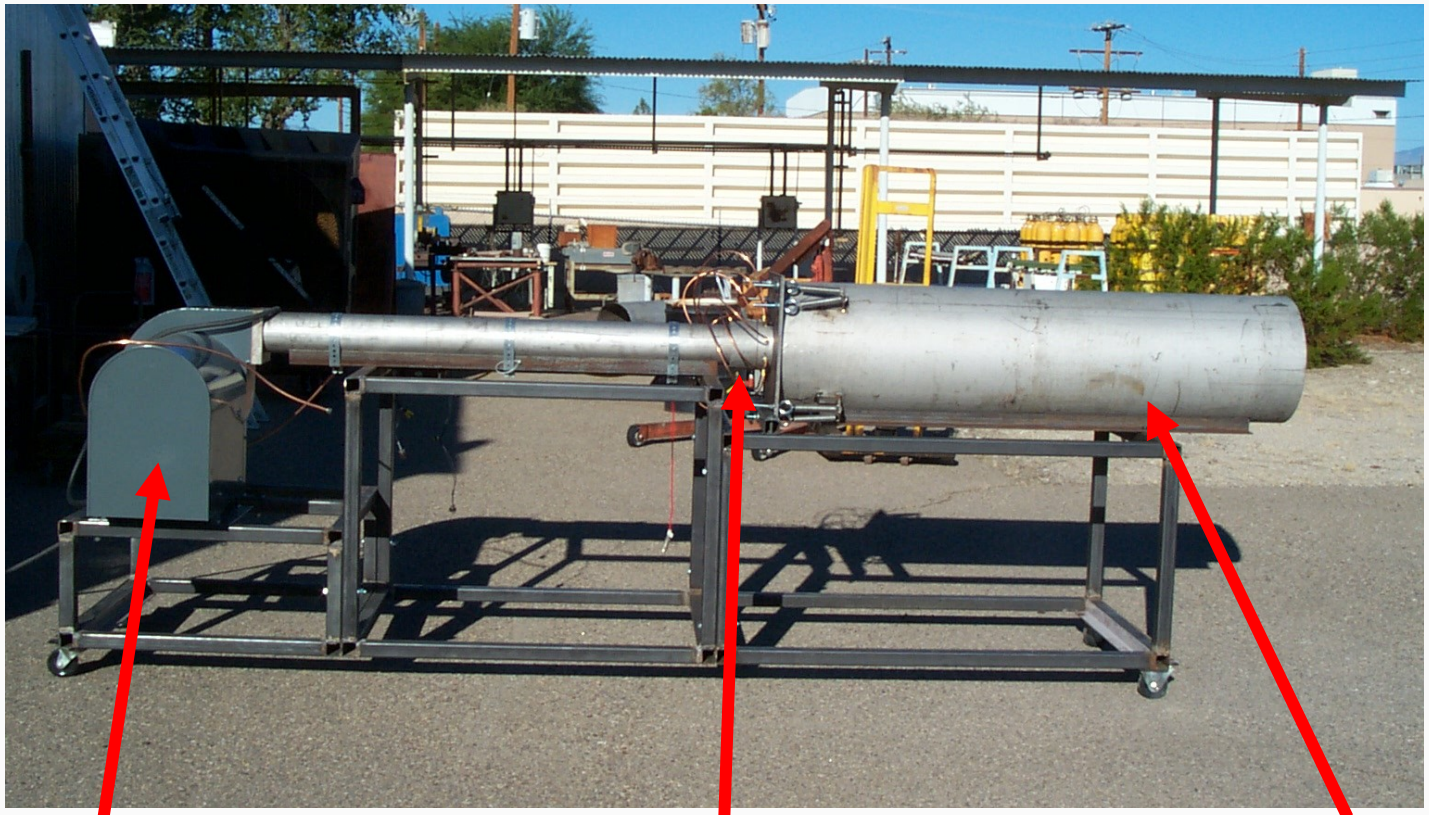
- **External fire test must be performed on full scale item in its shipping configuration**
  - **Problem with large solid rocket motors**
    - **Cost of the asset (>$30 million US)**
    - **Hazard associated with test performance**
      - **Difficult to secure propulsive item in its shipping container**
      - **Large amounts of liquid fuel required**
    - **Real estate required for test site**
    - **Single test on a probabilistic event**
      - **Results may be misleading**

Thermal Apparatus

Thermal Stimulus

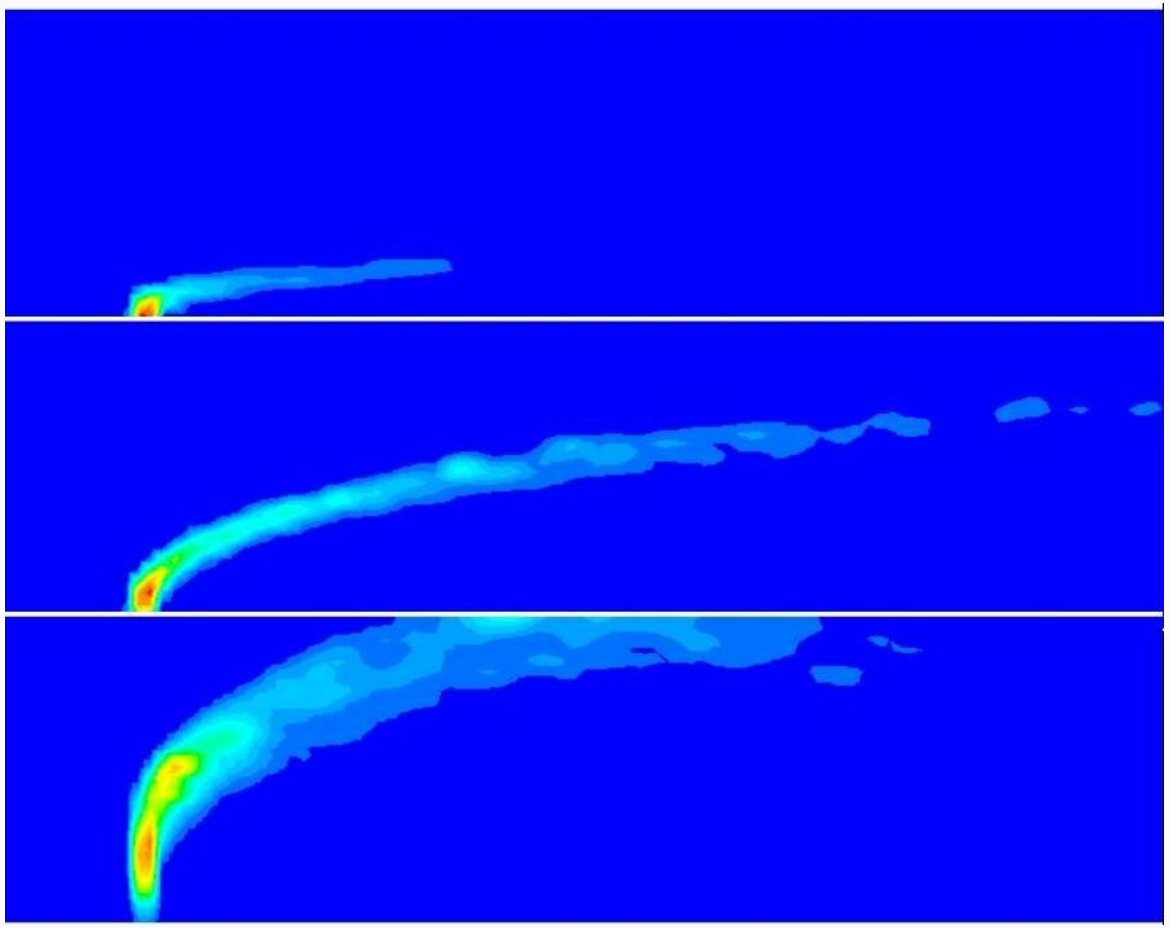
- **Fuel fires are difficult to describe and impossible to control**
  - **Alternate test should be controllable**
- **Flux in fuel fire varies from 20 to 200 kW/m² (SNL)**
  - **Credible to accident scenario**
    - **50, 75 and 100 kW/ m² have been selected**
      - **Lower flux and longer times represent conservative approach**

High Heat Flux Device



Computational Support

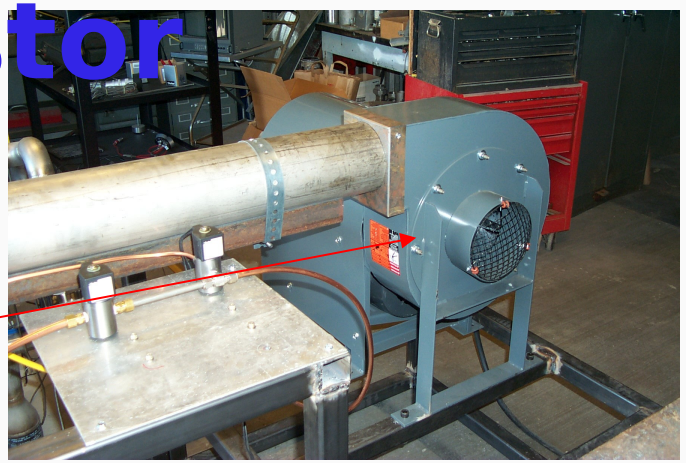
- **Injector diameter based on CFD calculations**

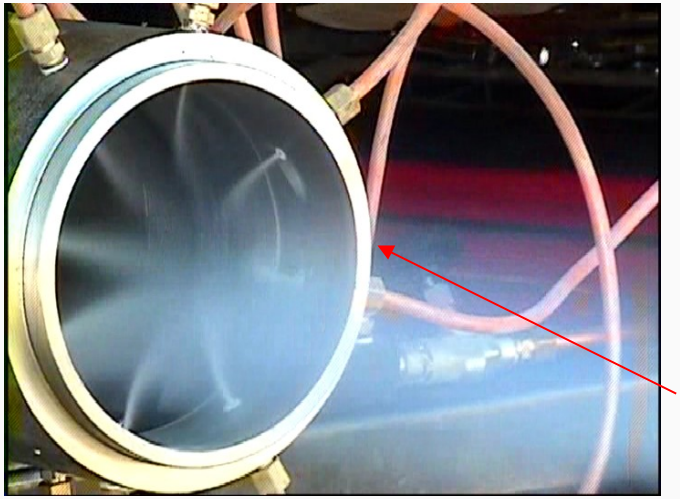


Heat Flux Combustor

System mounted on stand

Fan Assembly

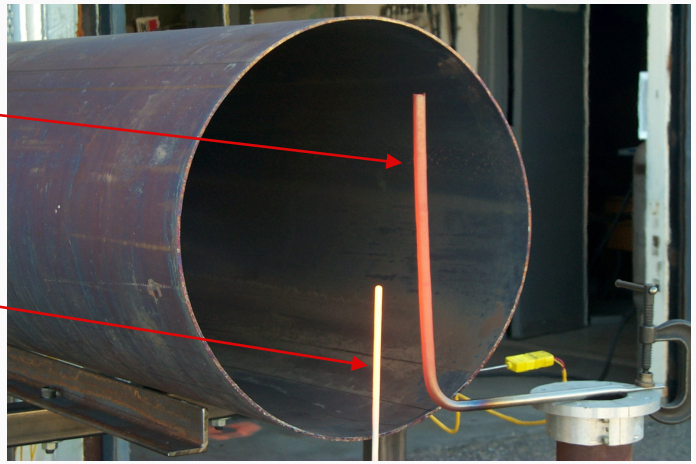




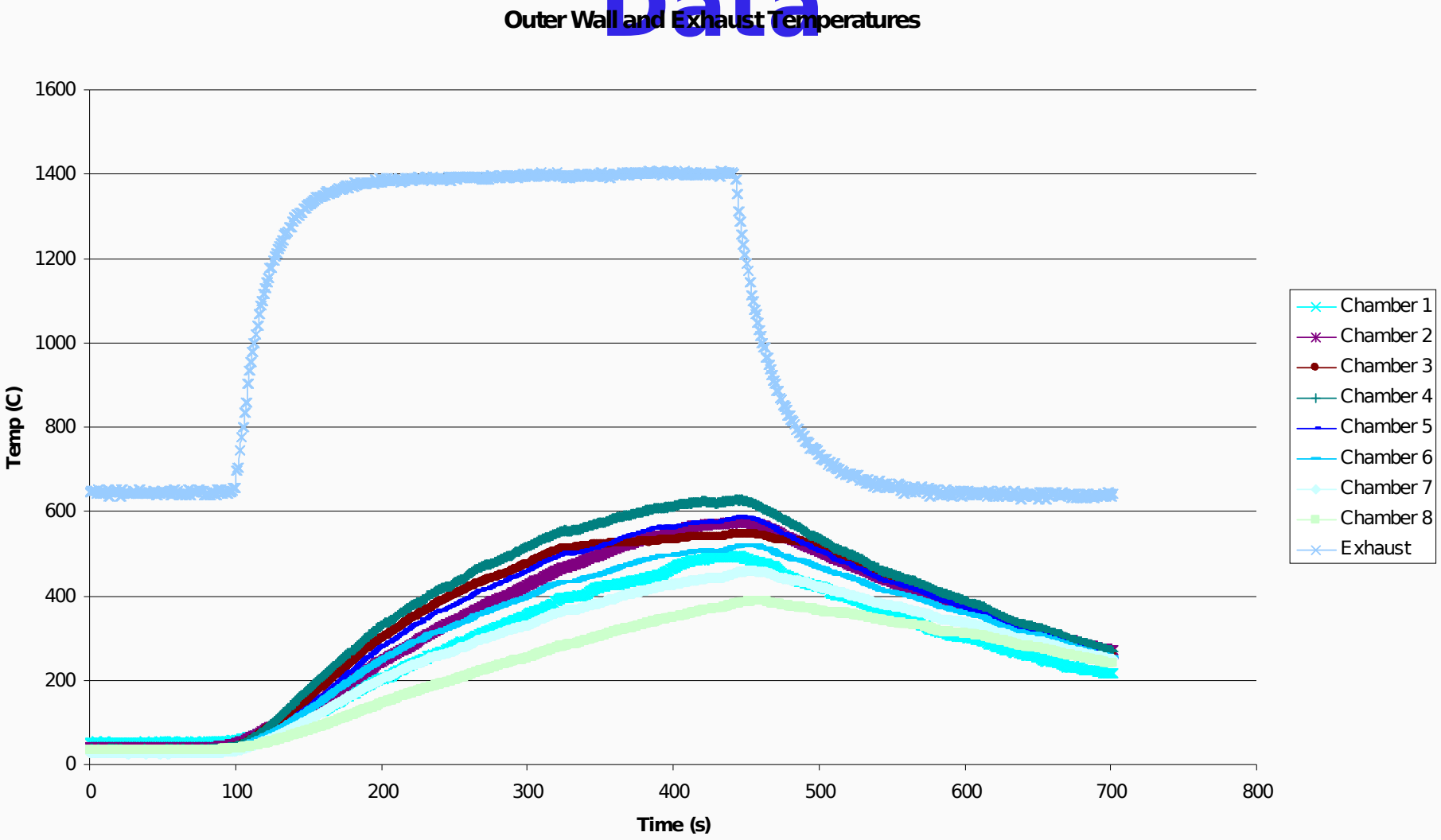
SS pipe

Exhaust TC

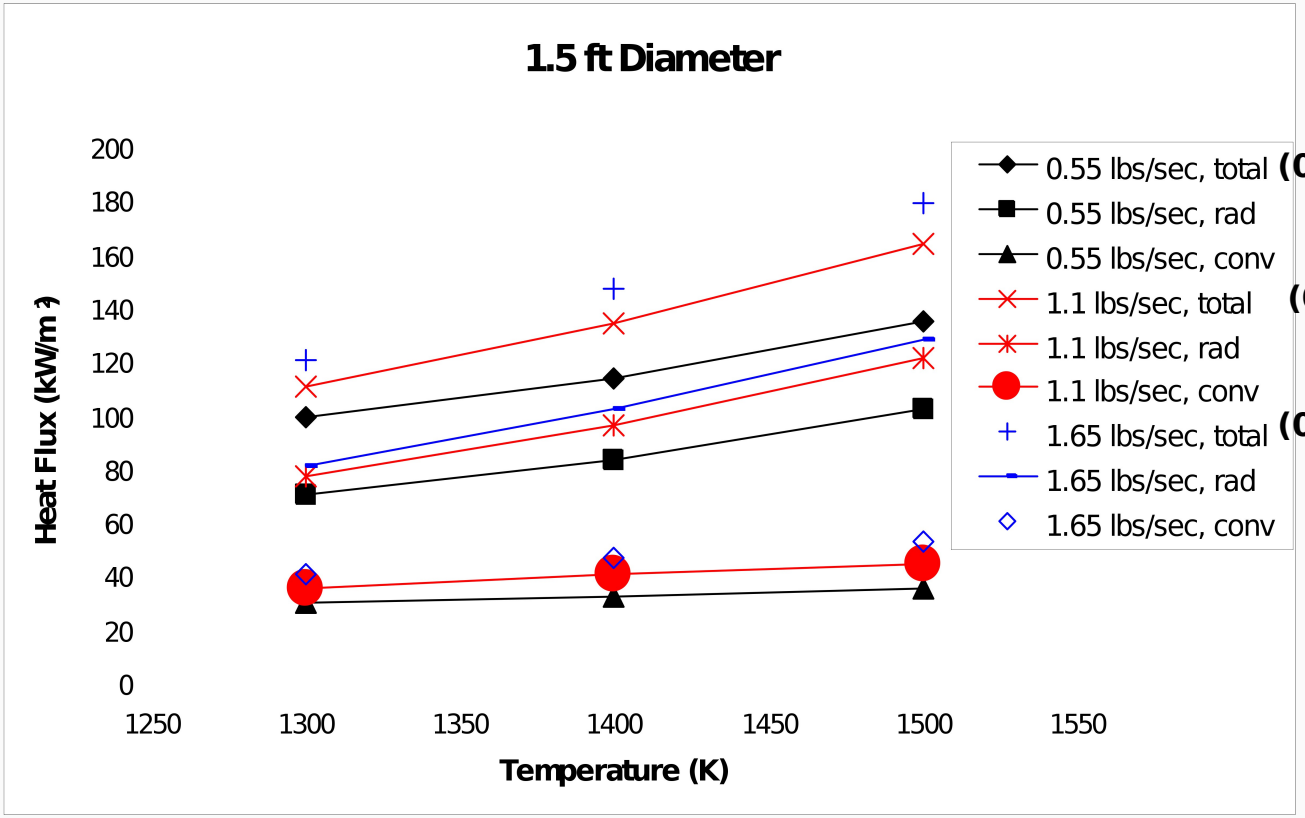
Liquid Propane Injection



Heat Flux Combustor Data

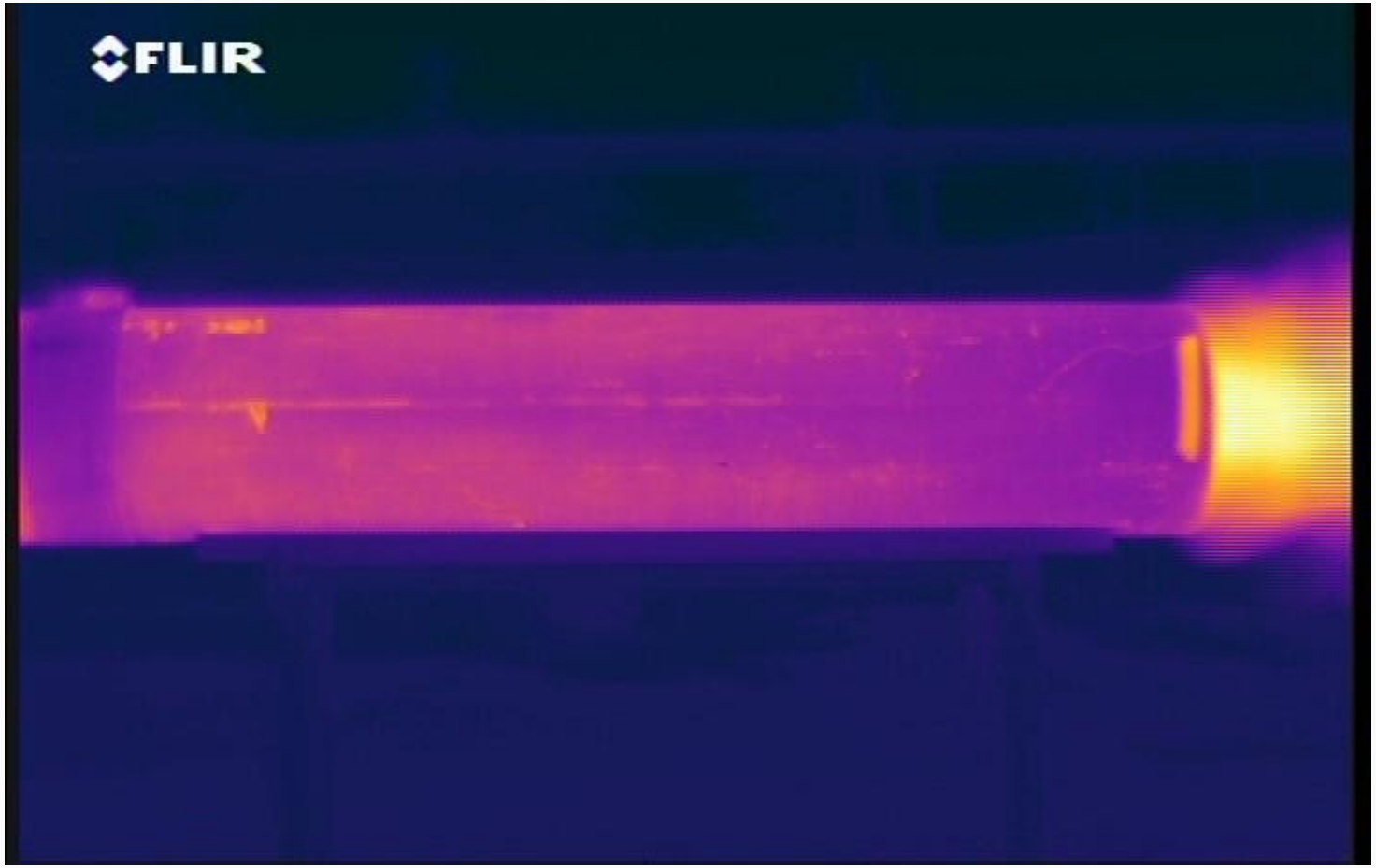


Heat Flux Combustor Predictions

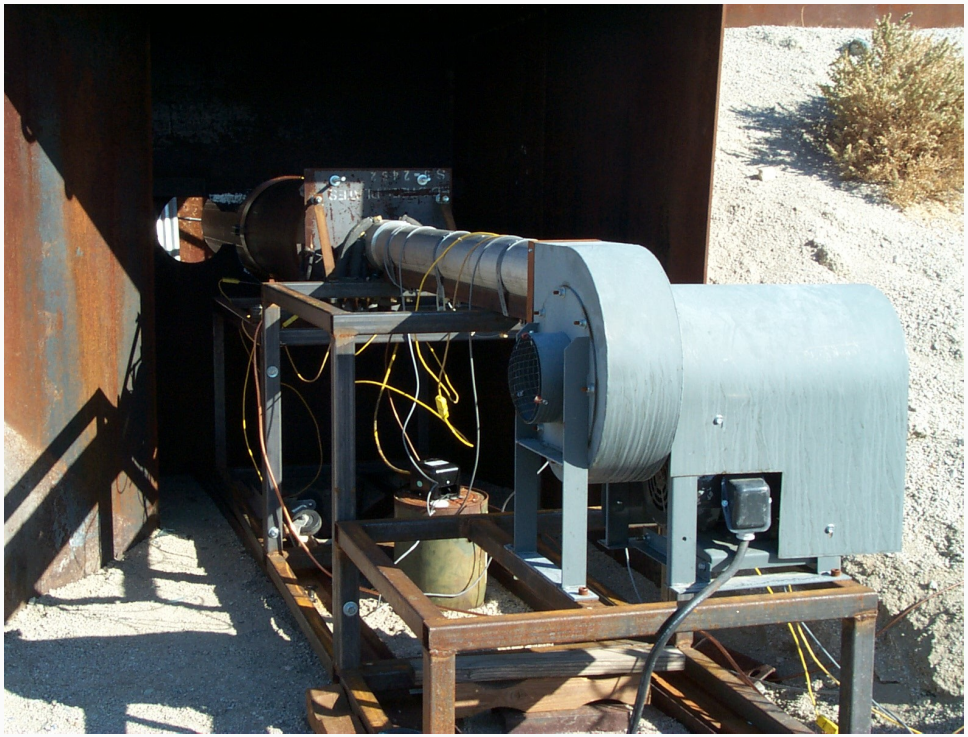


- **Heat flux calculations performed with Fluent**
- **Achieve a heat flux of at least 160 kW/m² with an exhaust temp of 1400 C (1670 K) and 1.1 lbs/sec**

IR Characterization

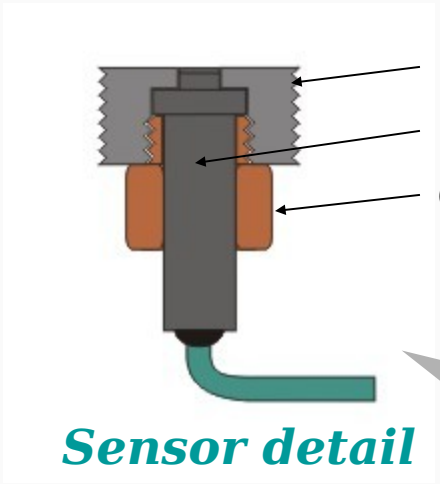


Combustor at Remote Site

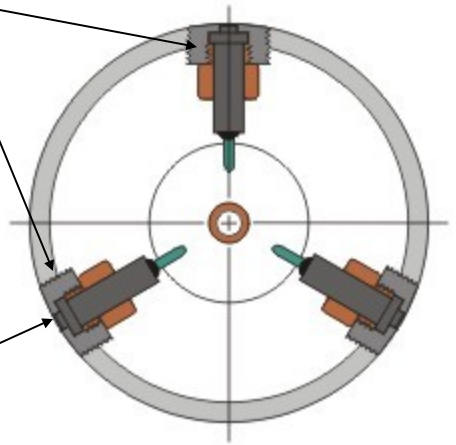


Calibration Device

Flux Calibration Concept

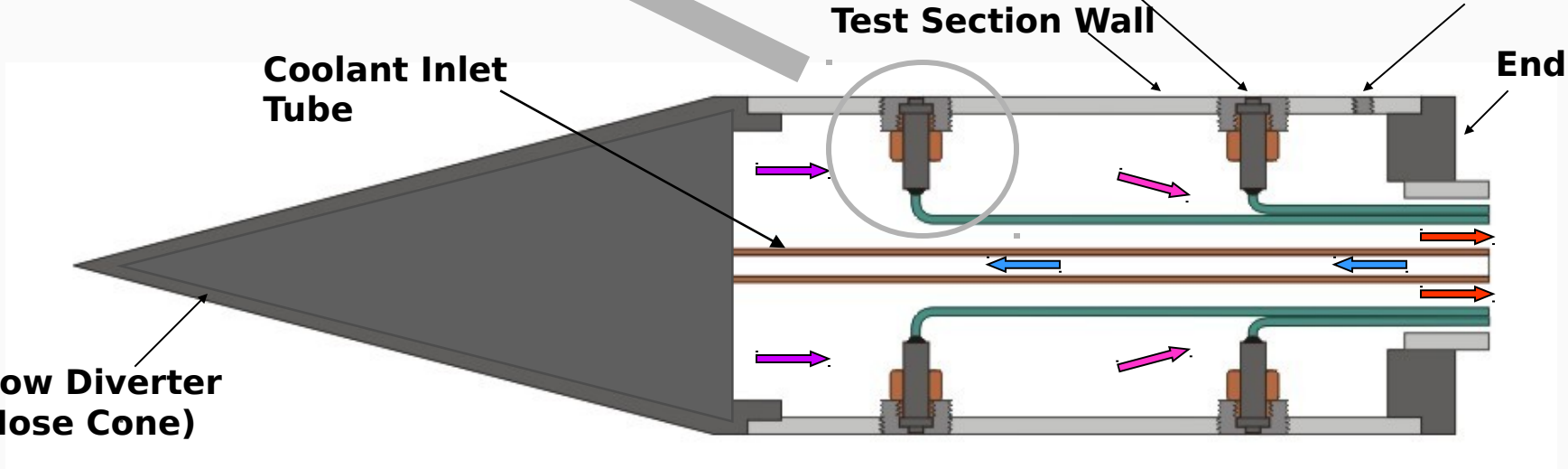


Sensor detail



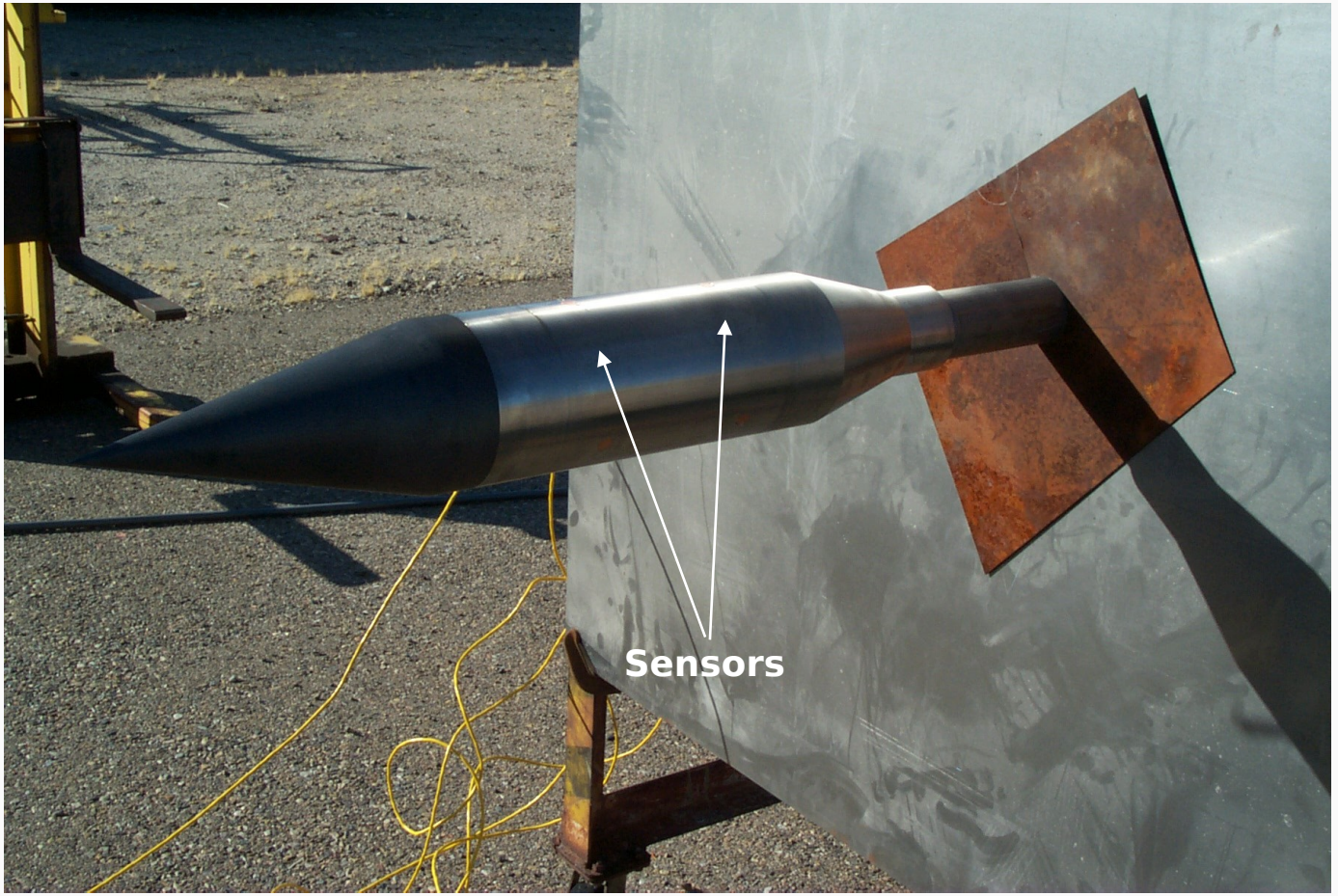
End view

Surface-Mounted
Heat Flux Microsensor (HFM)

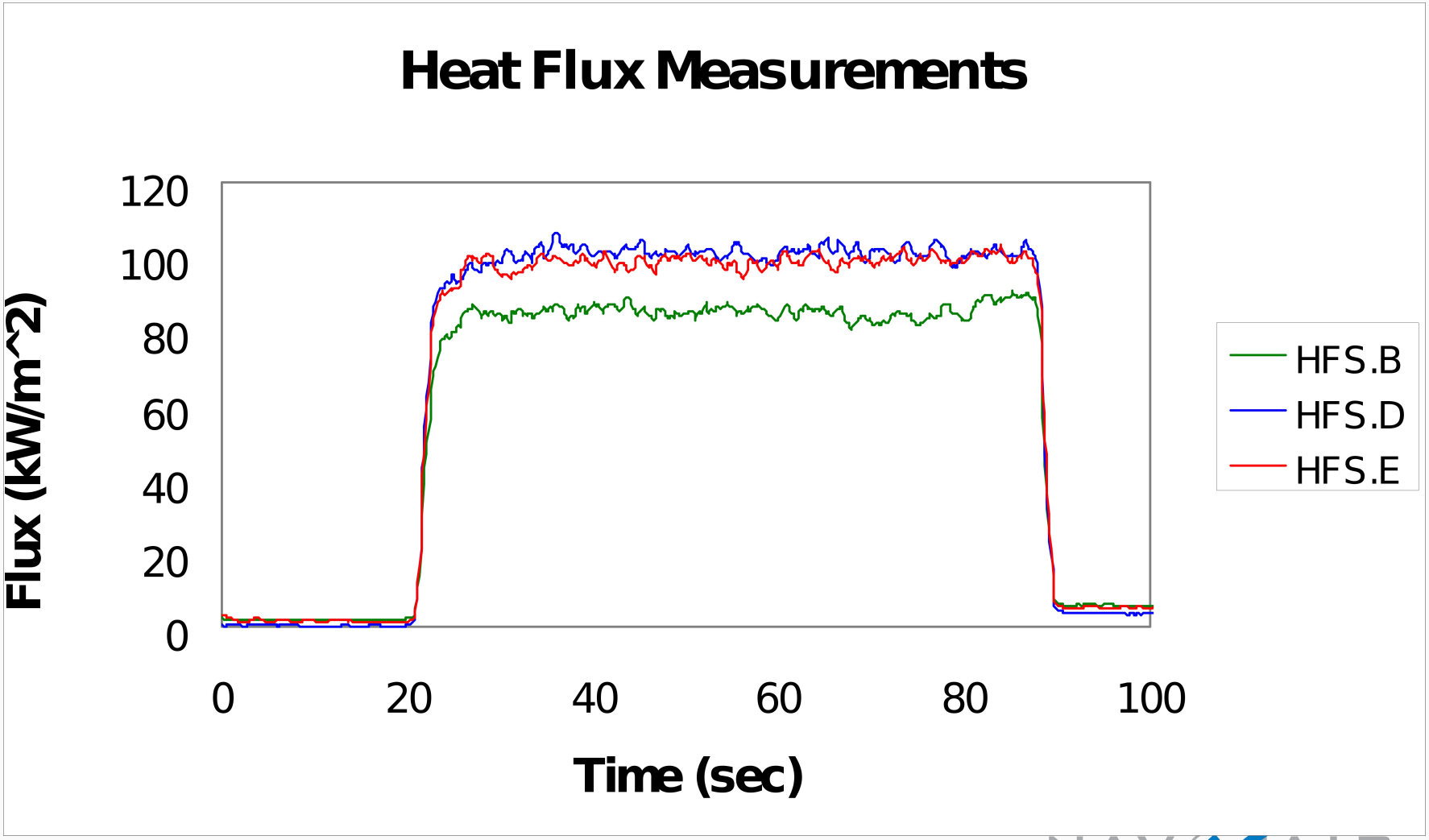


Cut-away side view

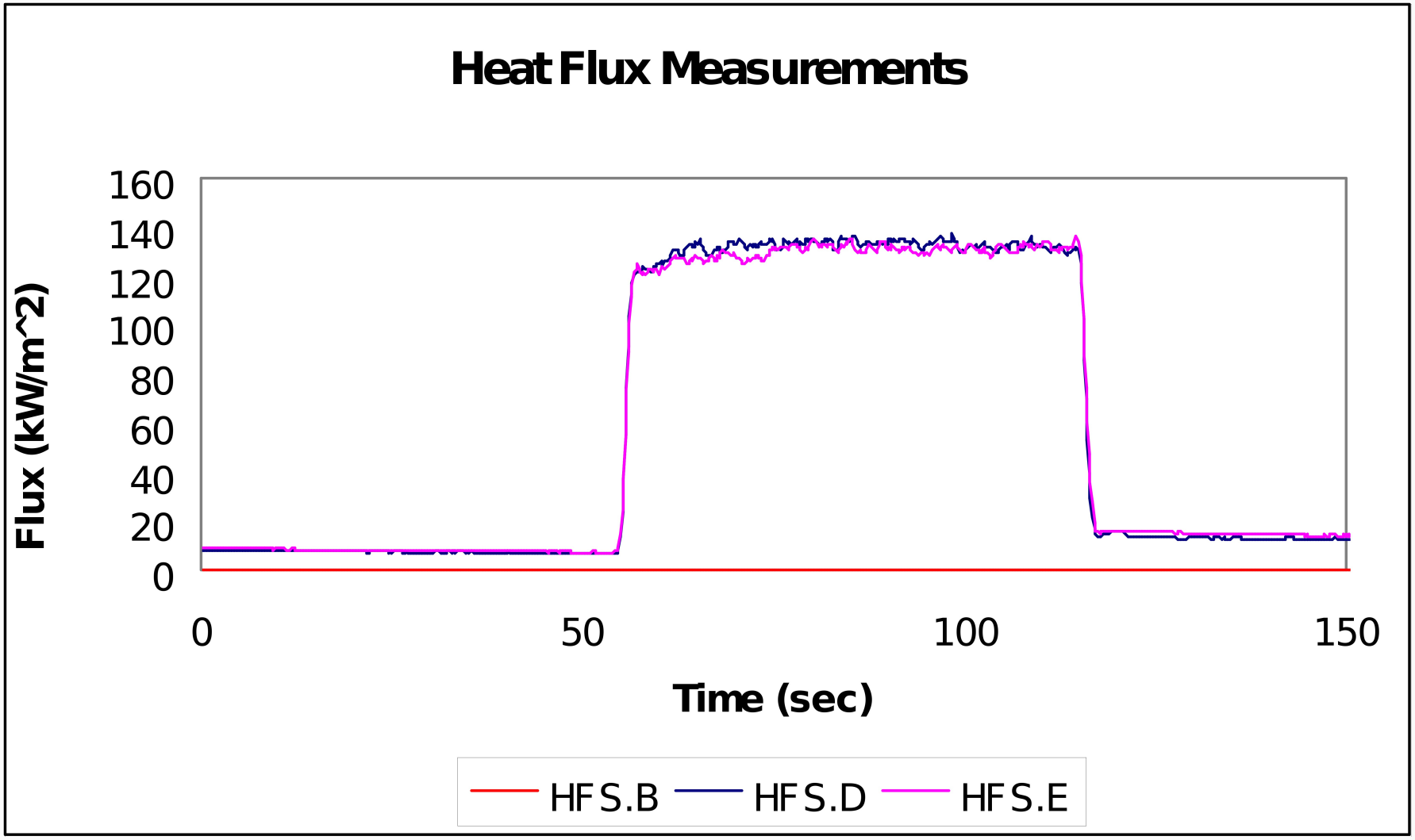
Calibration Device



Combustor Calibration – 100 kW/m²



Combustor Calibration – 135 kW/m²

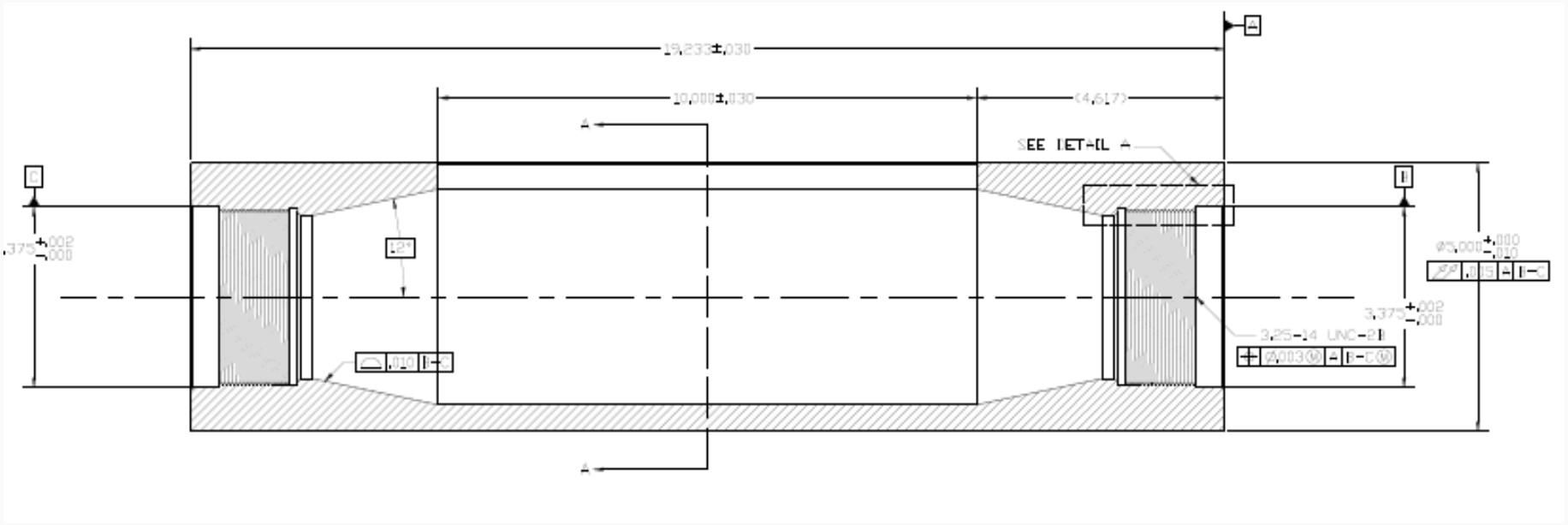


Test Article

Test Articles

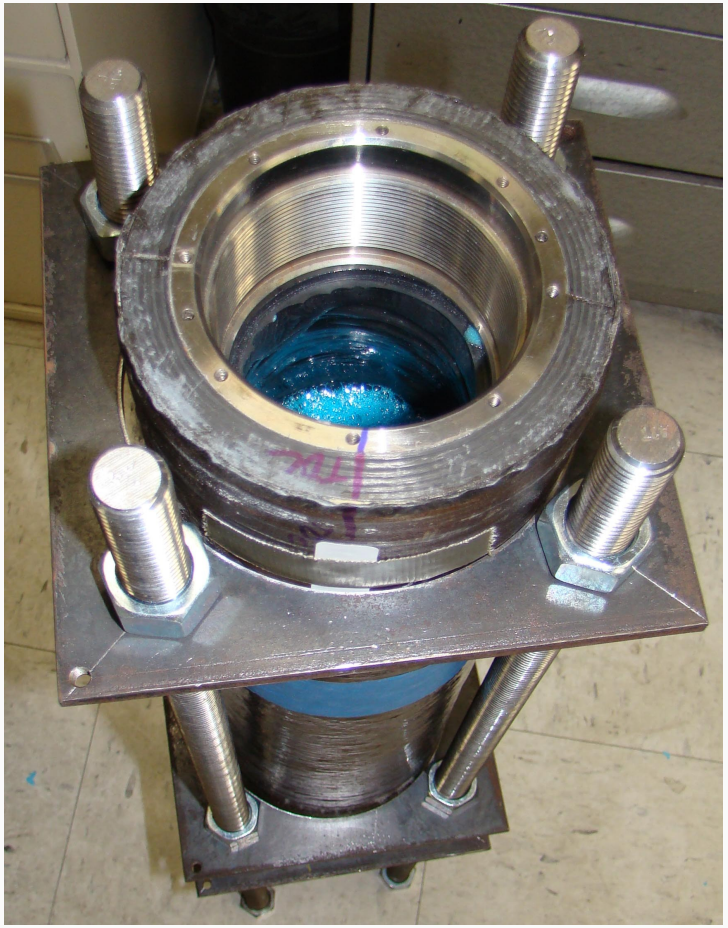
- **Cases insulated with EPDM and HTPB liner**
  - **Thermal properties of large diameter rocket motor**
- **2 cases (1 metal and 1 composite)**
  - **Inert loading**
- **1 metal case**
  - **AP/HTPB/Al propellant**

Test Article



Test Article Cases

Metal Inert



Composite Inert

Inert Articles Post Test

Metal Inert

Composite Inert

Live Firing

FAST COOKOFF
Metal Case
1.3 Propellant
20 September 2007
NAWCWD, China Lake

Summary

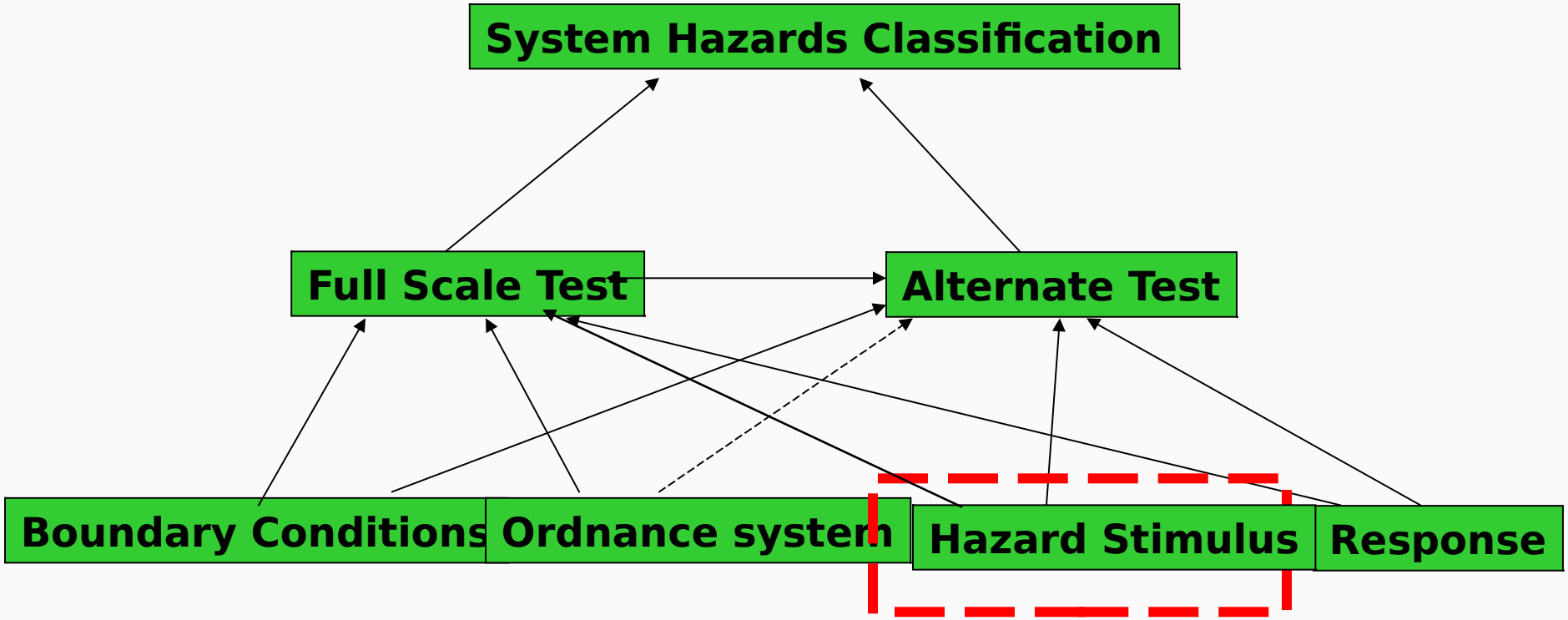
- **Thermal Apparatus – designed to produce 20-200 kW/m²**
  - **Controllable and Reproducible**
  - **Test article uniformally exposed to heat flux**
- **Calibration demonstrated capability from 50 – 150kW/m²**
- **Testing**
  - **Inert Characterization (Metal & Composite)**
  - **1.3 propellant in metal case**

Future Plans

- **Analyze the TC measurements of inert and live tests**
- **Complete testing**
  - **Live test articles (Composite Case)**
- **Validate flux level measurements with fuel fire**
- **Correlate model predictions with test data**

Extra Slides

Overall Approach

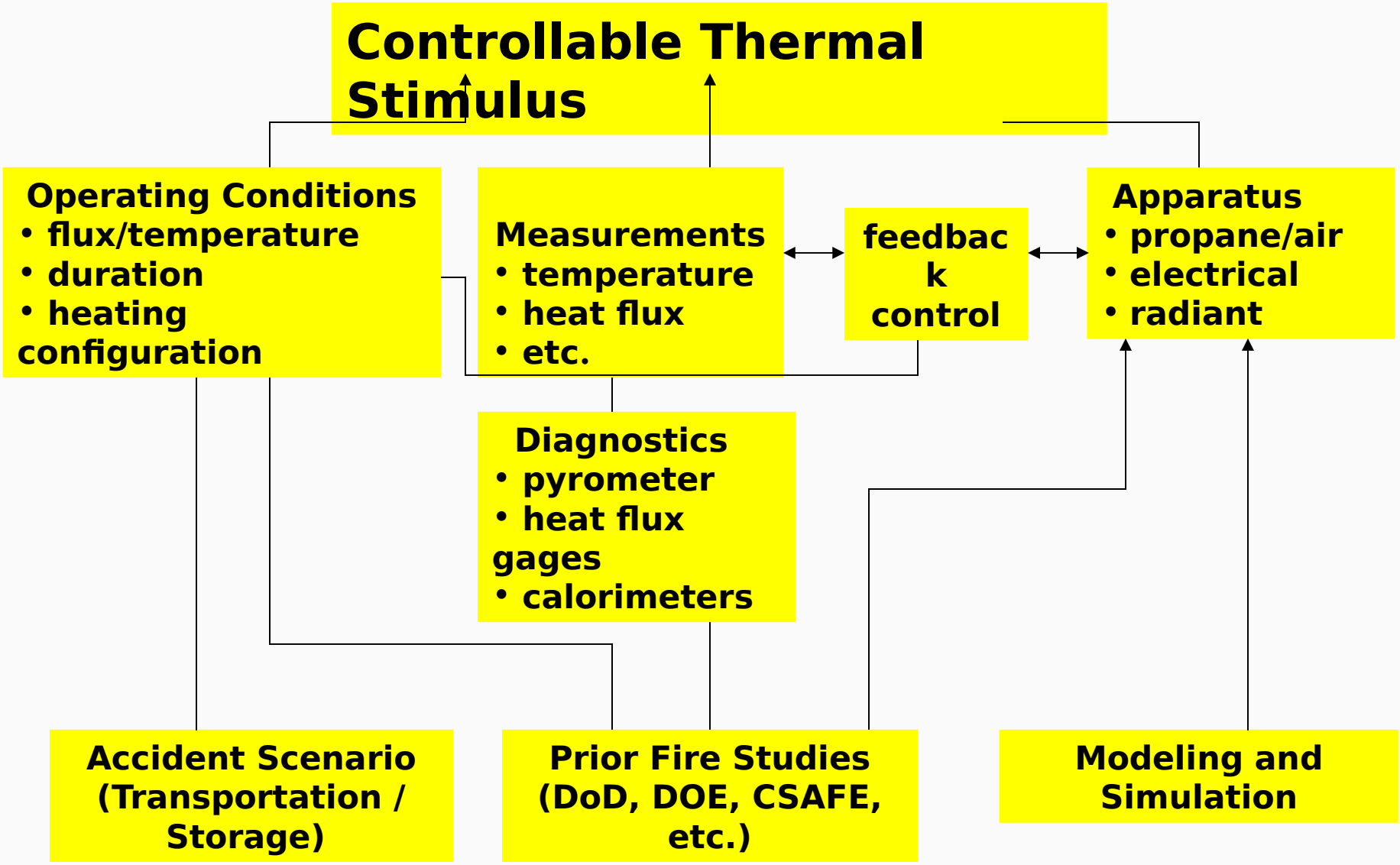


Final Hazard Classification

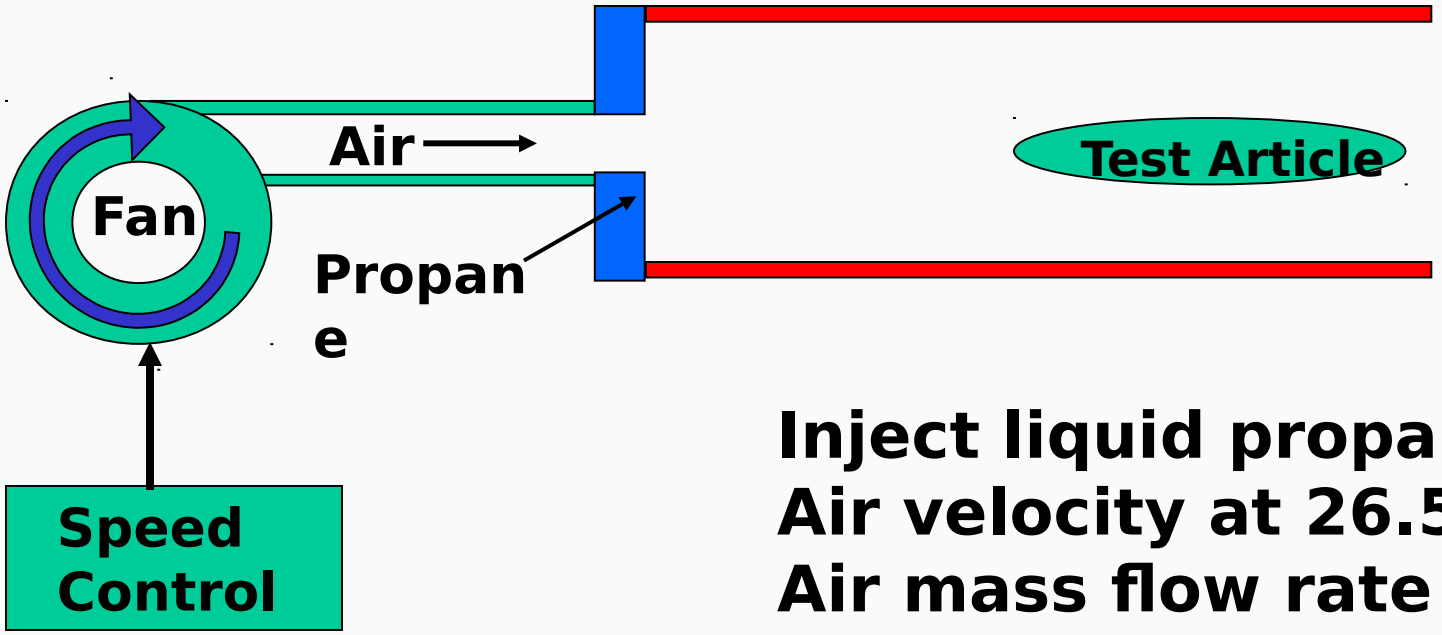
- **Perform system level tests (UN tests)**
- **Perform approved alternate test**
  - **Only shock tests approved as alternate for sympathetic detonation**
  - **No approved alternate tests for external fire**
- **Recommend an alternate test to service hazards classifier**
  - **Results must meet approval of Joint Hazards Classifiers and DDESB**

Three System Level Tests

- **Assignment of HD 1.1 through 1.4**
  - **Single Package**
  - **Sympathetic reaction**
  - **Liquid fuel/external fire**

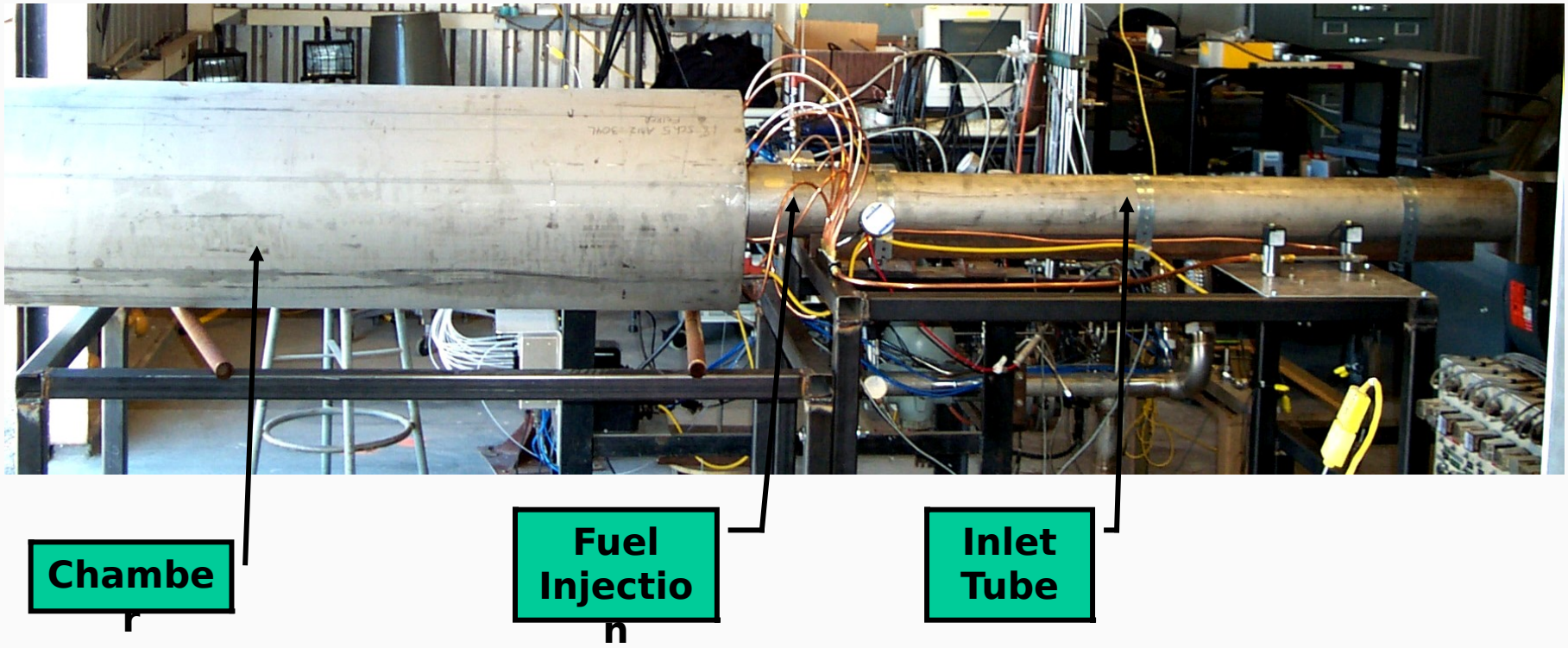

Controllable Thermal Stimulus
Operating Conditions
• flux/temperature
• duration
• heating configuration
Measurements
• temperature
• heat flux
• etc.
feedback control
Apparatus
• propane/air
• electrical
• radiant
Diagnostics
• pyrometer
• heat flux gages
• calorimeters
Accident Scenario (Transportation / Storage)
Prior Fire Studies (DoD, DOE, CSAFE, etc.)
Modeling and Simulation

Heat Flux Combustor

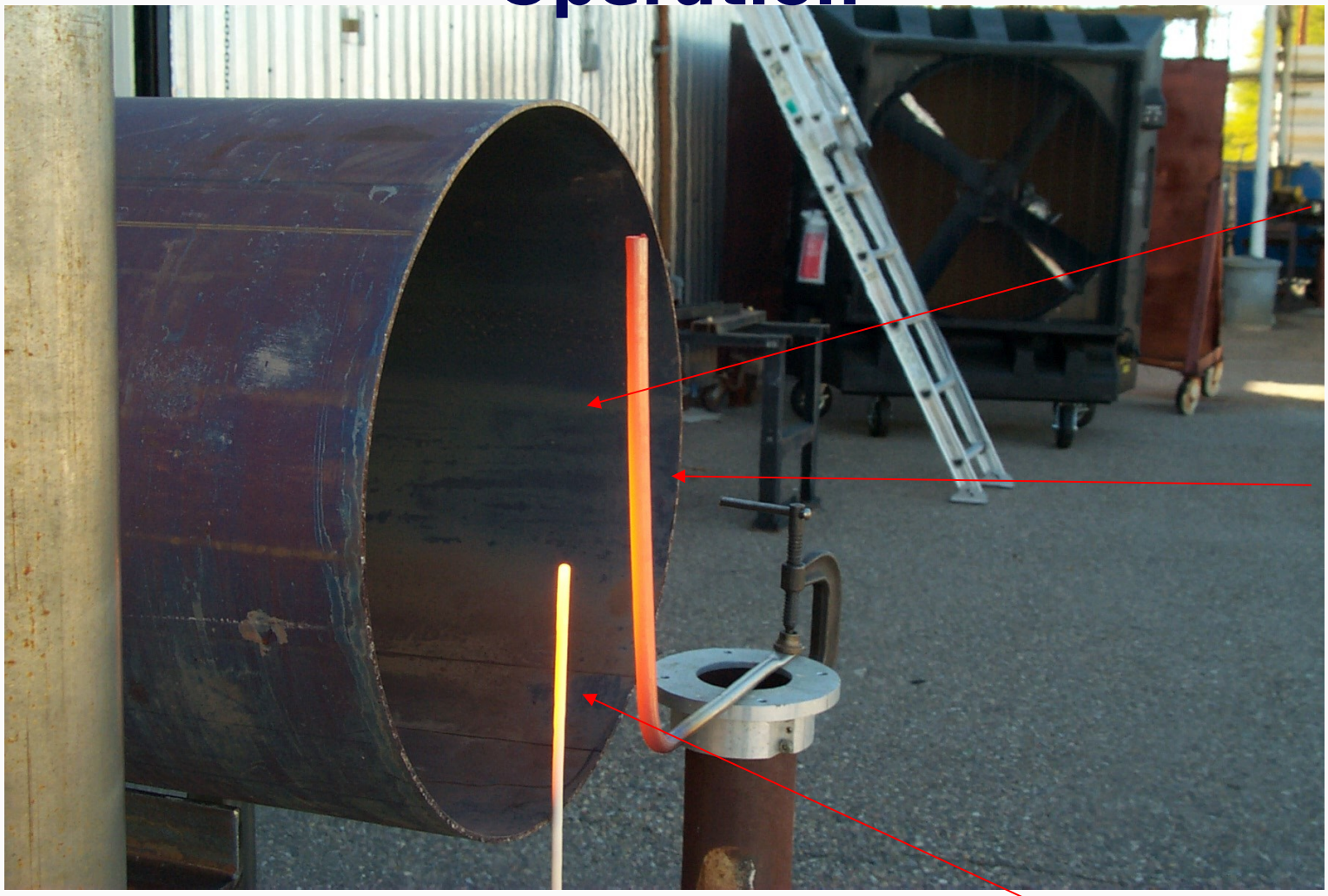


Inject liquid propane at 2.9 l/m
Air velocity at 26.5 m/sec
Air mass flow rate of 2.2 kg/se
Temperature = 1427 deg C

Heat Flux Combustor



Heat Flux Combustor in Operation



Need for Flux Level Calibration

- **The Constant Heat Flux Device (CHFD) is tunable, but requires calibration and verification**
  - **Fuel ratio and fan speed need to be determined for different heat flux levels (calibration)**
  - **Heat flux needs to be measured to ensure that it is uniform at the specimen's radial surface (verification)**
- **Without direct flux measurements**
  - **Introduce uncertainty**
- **Measurement of repeatability and uniformity**

Calibration Insertion Device

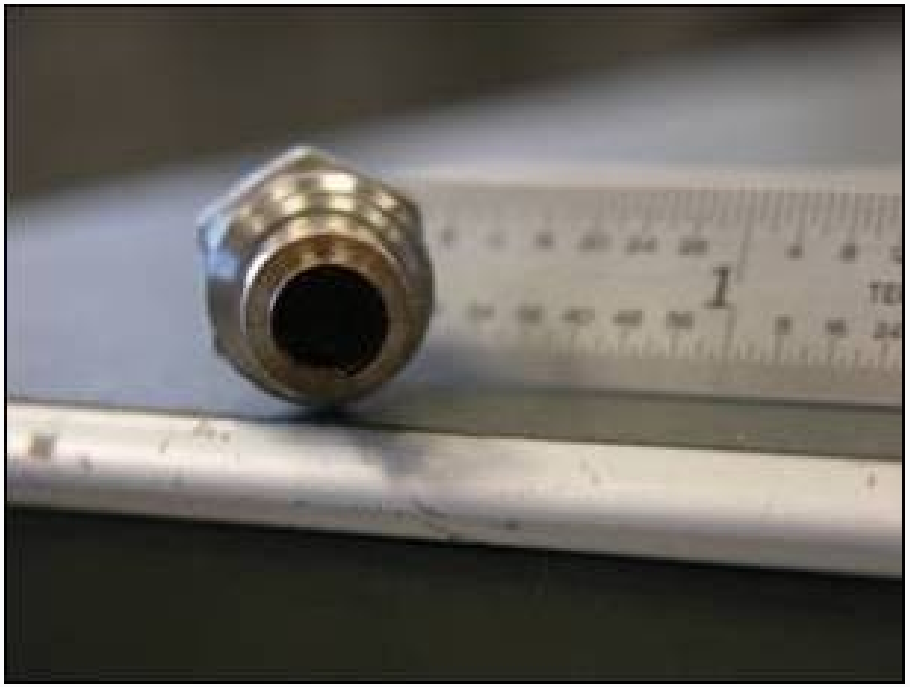
Flux Calibration Device

- **Must be similar in shape and scale to the test article**
- **Multiple surface heat flux measurements**
  - **Effective average heat flux**
  - **Reduce uncertainty**
- **Liquid cooling due to the large imposed heat flux (up to ~100 kW/m^2)**
- **Flow diverter (nose cone) to ensure uniform heat flow over outer surface**

Heat Flux Microsensors

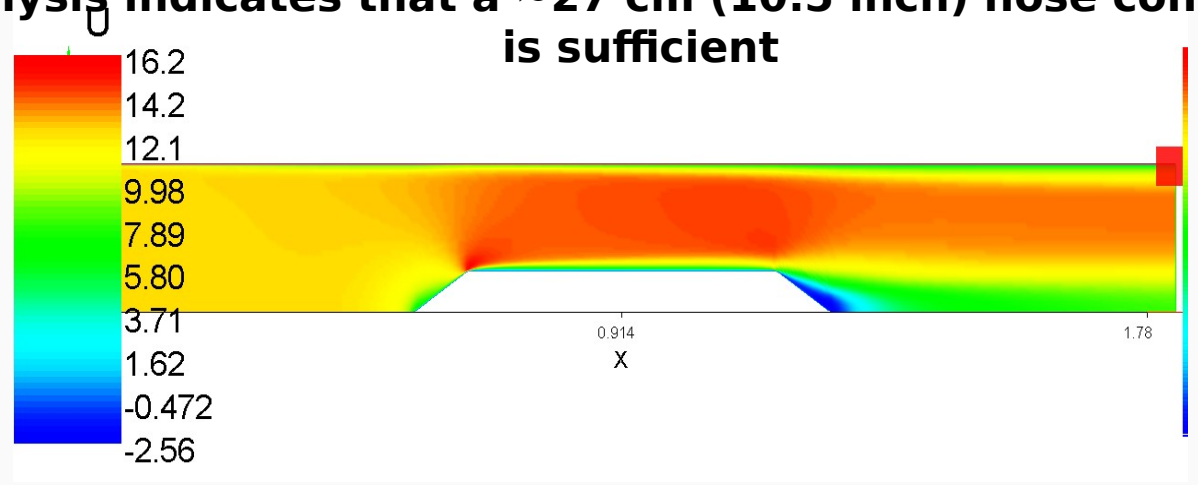
- **Measuring heat flux is difficult and is device and technique dependent**
- **Simultaneous measurement of the total heat flux and the surface temperature**
- **Heat flux from radiation and cross flow convection**
  - **Gardon gauges are erroneous in cross flow convection**
- **Rapid response times (17 μs uncoated, 300 μs with surface coating)**
- **Can be liquid or conduction cooled**

Heat Flux Microsensor

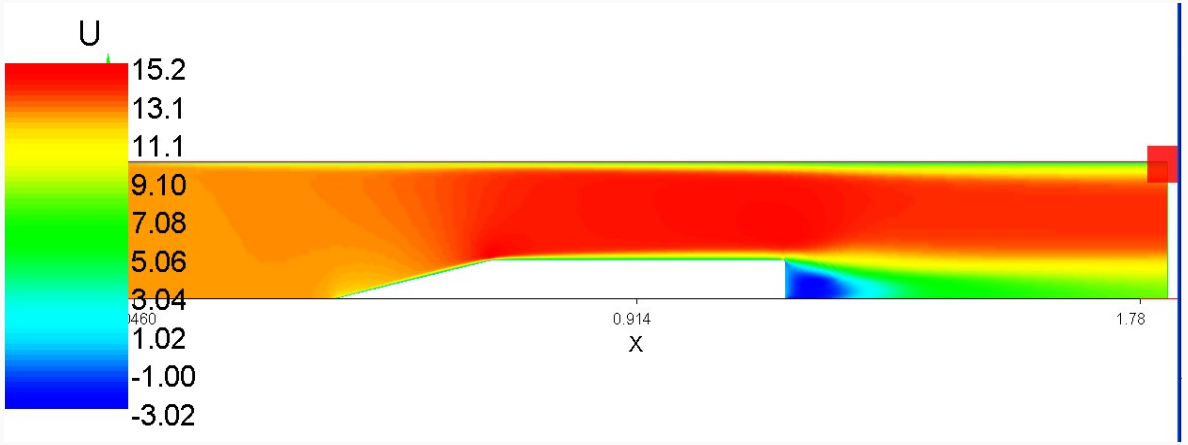


Flow Diverter Design

- **Using the largest air velocity, several cone lengths were analyzed, ~9 cm (3.5 inch), ~18 cm (7.0 inch), and ~27 cm (10.5 inch)**
- **Analysis indicates that a ~27 cm (10.5 inch) nose cone length is sufficient**

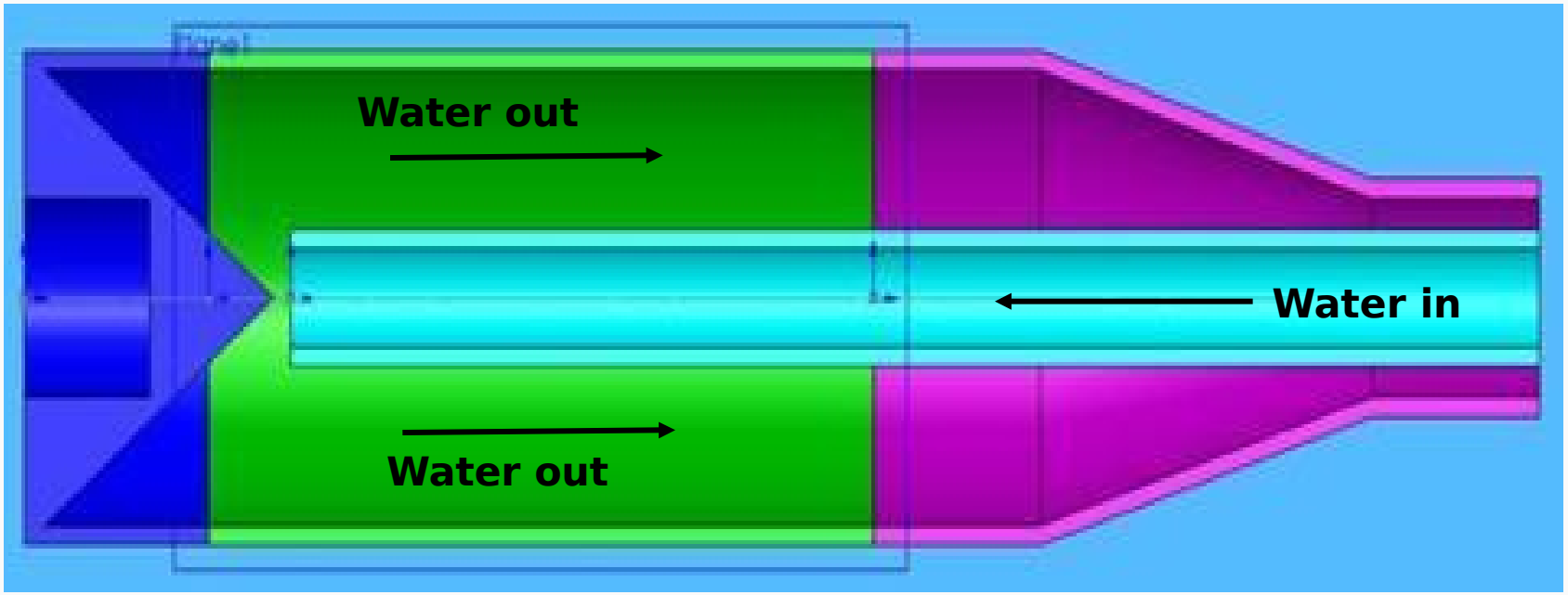


3.5 inch



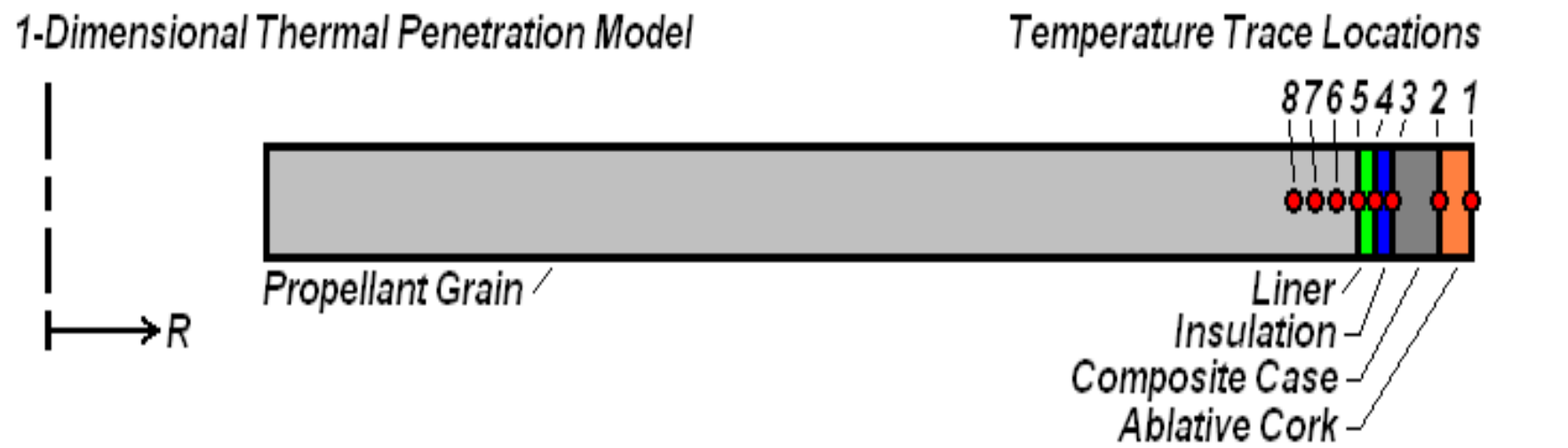
10.5 inch

Flow Schematic



Test Article

- **How small can we make it?**
  - **Created transient Thermal penetration model**
    - **MP Coyote – SNL**
    - **Used case/inslulator geometry and properties of a large diameter rocket motor**
    - **Compare to 18, 7 and 2.4 inch propellant web**
    - **Neglected char**



Test Article

- **Calculations indicate that propellant web thickness can be reduced as long as the insulator/case/ablative thicknesses remain constant**

Summary

- **Thermal apparatus**
  - **Constructed liquid propane/air burner**
    - **Modular and easy to modify**
    - **No single part exceed $1000**
    - **Does not require high pressure air at test site for 0.5 Kg/sec (1.1 lb/sec) flow**
      - **Fan requires 15 amp/208 volts**
  - **Generates 20 to 200 kw/m^2 heat flux**
  - **Convective and radiative heat components controlled**

Summary

- **Thermal Apparatus**
  - **Test article always surrounded by consistent conditions (i.e. surrounded by duct and insulation, less impact of wind and temperature fluctuations)**
  - **Surrounding duct can act as witness plate for fragments, ability to characterize fragments**
  - **Can accommodate up to ~23 cm (9 inch) diameter test article with current chamber**
  - **Will not interfere with degradation of composite case**

Summary

- **Calibration Device and Test Article**
  - **Require a flow diverter on forward end**
  - **Calibrate to determine heat flux at test article**
    - **Must be same shape**
  - **Calibration device uses heat flux microsensors**
    - **Must be cooled**
  - **Composite test article to simulate case of large diameter rocket motor**
    - **Outer layer of device is most critical**
    - **Longitudinal “flaw” for case failure at ~2000 psi**
- **Computational tools have been applied to all aspects of the experimental design**